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**CALLISTO DEMONSTRATOR: Focus on system aspects**

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**Abstract**

Japan and Europe are currently developing their new competitive launchers that are planned to enter into operation very soon, and they are based on expendable concepts. In the same time, reusable concepts are successfully operated in USA. Reusability could be the solution for further improvement of competitiveness of future launch system. Then, one of the main question we have to address is “do we master the technics and technologies necessary to recover and to reuse part of launchers?”.

This is why, in order to assess the technical difficulties and potential benefits of reusability, CNES, DLR and JAXA have decided to joint their competences and their efforts in the development of a scaled reusable VTVL in-flight demonstrator dubbed CALLISTO (Cooperative Action Leading to Launcher Innovation in Stage Toss - back Operations), allowing to recover and reuse the vehicle under conditions representative for an operational launcher.

CALLISTO vehicle is about 13 m high and 1.1 m diameter, propelled by a JAXA LOX/LH2 engine able to reignite in flight and with throttling capability. It will be operated from the French Guiana Space Centre and sized for about 10 flights following different mission profiles, opening the flight domain from low altitude test up to a full demonstration profile. CALLISTO will be launched from the DIAMANT site and will land on the same site.

This paper will provide an overview of the project and its missions after the System Preliminary Definition Review,. This paper will address: 1) Architecture design activities focusing on: Trajectories satisfying demonstration objectives as well as operational constraints, the definition of the flight domain due to multiple mission profile, flying qualities during descent phase, including aero-shape design, flight control and management of different actuators, 2) CONOPS focusing on safety critical operations before lift-off and after landing, and associated means 3) Maintenance, Repair and Operations guidelines 4) Different products and module definition and in particular the management of COTS 5) Ground segment definition

**Keywords:** Callisto, Reusable, Demonstrator

**Acronyms/Abbreviations**

ALS	Approach and Landing System
COTS	Component Out of The Shelf
CSG	Guiana Space Centre
DAU	Data Acquisition Unit
DLP	Drag Landing Point
FCS-A	Flight Control System-Aerodynamic
FCS-R	Flight Control System-Reaction
FCS-V	Flight Control System-Vectoring
FNS	Flight Neutralisation System
GNC	Guidance Navigation & Control
GNSS	Global Navigation Satellite System
H2O2	Hydrogen Peroxide
HNS	Hybrid Navigation System
LH2	Liquid Hydrogen
LOX	Liquid Oxygen
MRO	Maintenance, Repair, Overhaul
NRC	Non Recurring Cost

OBC	On-Board Computer
PDR	Preliminary Design Review
PSDB	Power System Distribution Box
RC	Recurring Cost
TRL	Technology Readiness Level
VEB	Vehicle Equipment Bay
VPH	Vehicle Preparatory Hall
VTVL	Vertical Take-off Vertical Landing

**1. Introduction**

Reusability of launch vehicles is a potential measure to substantially reduce launch service costs ([R1]) and open up new possibilities for space.

JAXA, CNES, and DLR have shared the common view that a reusable vertical take-off and vertical landing (VTVL) first stage is a promising concept as the first step of reusability as demonstrated

successfully by Space-X. Then, the three agencies have performed joint activities for a scaled reusable VTVL demonstration vehicle to master key technologies necessary for recovering and reusing first stage.

This demonstrator will pave the way for the design of successor to Ariane 6 in Europe and H3 in Japan.

The demonstrator and project are called CALLISTO, which stands for Cooperative Action Leading to Launcher Innovation for Stage Toss-back Operations. The Phase-A feasibility study was completed in March 2018. The phase B at system level was completed in December 2019 with the System Preliminary Design Review.

The System in the CALLISTO project consists of the vehicle itself, the launch complex and the launch bas.

This paper presents a broad overview of the CALLISTO project.

## 2. Organisation

JAXA, CNES, and DLR constitute a joint team to promote the development of the CALLISTO system.

The joint team is organized based on equal partnership, and project management leaders and technical leaders are shared among the three agencies. Management the CALLISTO project is a challenging task, because the three agencies are geographically separated, and technical backgrounds, culture are very different among joint team members and entities. After several years, we have learned working together and frequent face-to-face meetings/workshops are very efficient for mutual understanding and for the decision process based on consensus.

The work sharing among the three agencies has been defined considering each agency's technical interests and background. Figure 1 shows the main elements of the CALLISTO system and development responsibilities for each element. CNES is leading the vehicle system design and system requirements including interfaces, the ground segment development and CSG operations. CNES is also responsible of the avionics architecture and the Flight Termination System, requested by flight safety.

JAXA is responsible for the engine and the Fluid Propulsion System with associated equipment and avionics parts. JAXA is also responsible of the LOX tank, vehicle integration and firing tests in Japan.

DLR is responsible of the navigation, the aerodynamics and aerothermodynamics, the FCS-A and the landing system. DLR is also responsible of the LH2 tank, the VEB and Nose Fairing structure as well as FCS-A and ALS product with their associated avionics equipment.

One of key technologies in the CALLISTO project is guidance and control and the achieved accuracy. The three agencies are interested in guidance and control

software, so two versions of guidance and control software and two OBC will be developed and flight-tested: one by CNES while the other jointly by JAXA and DLR.

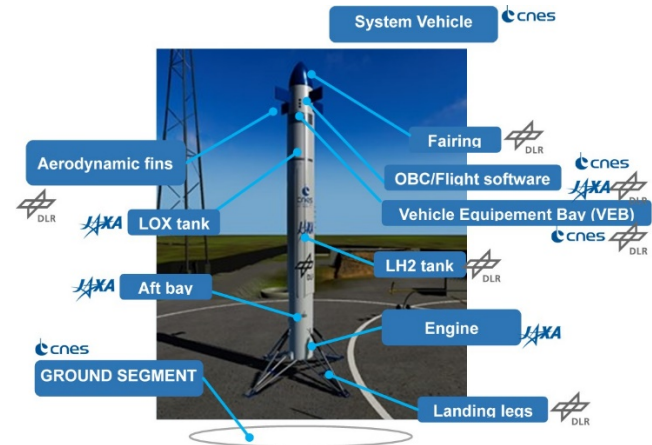


Fig. 1 Main elements responsibilities

## 3. Objectives

The CALLISTO project objective is to obtain flight and ground data to verify the feasibility and potential interest of a future reusable VTVL first stage.

The overall goal is to demonstrate the capability to recover a vehicle in toss-back (or boost-back) and vertical-landing modes as well as turnaround operations linked to refurbishment and reuse with the aim to explore the overall mission cycle of a reusable first stage.

The mission requirements on flights are defined as:

- Land on a designated landing area, following a flight sequence including: a propelled ascent phase and a return phase including a boost-back manoeuvre and a re-entry phase such that the transonic region is crossed.
- Demonstrate the capability to perform the sequence covering the flight conditions experienced by an operational reusable VTVL first stage: attitude manoeuvre at low dynamic pressure and minimized propellant re-conditioning duration.
- Perform a landing boost with a minimum non-gravitational acceleration of 1.3 g at least during one flight.

A landing with a non-gravitational acceleration of more than 1g (this means that the engine thrust is greater than the force of gravity) is an important technique to save amounts of propellants.

In addition, for CNES, there is the objective to demonstrate the capability to operate a reusable vehicle, representative of a 1<sup>st</sup> stage, at CSG. The selected take-off and landing site is the former DIAMANT site.

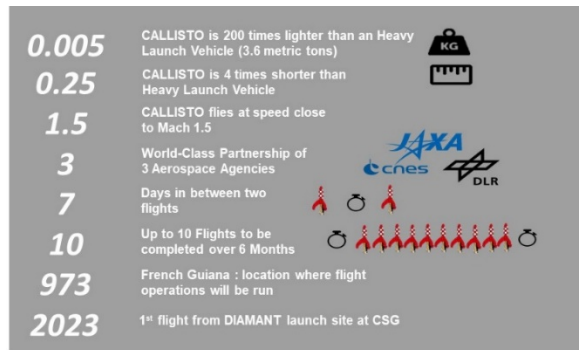
## 3. Quick overview

CALLISTO can be summarised with some key numbers reflecting its specificities and challenges.

The four main challenges are:

- To manage the constraints generated by the small size of the vehicle compared to a heavy launcher. The constraint is driven by the choice of the engine.
- As a consequence, to achieve the high level objectives
- To fulfil the very demanding operation and MRO plan in terms of schedule
- Last but not least to be able to develop such project through a cooperation between three agencies.

This is a challenge but also a chance to bring and gather so huge competences and experience.



#### 4. System design

CNES is leading the CALLISTO system design with the support of DLR and JAXA.

##### 4.1. Mission design

Objectives assigned to the flight profiles of CALLISTO experimental vehicle are demonstration of accuracy down to metric precision for flight profiles involving supersonic re-entry as well as boost-back manoeuvre, and demonstration of in-flight propellant management.

CALLISTO flight profiles are characterized by a large number of state changes (engine on/off, fins folded/unfolded, legs folded/unfolded) leading to strong interactions at system design level.

Different mission profiles were studied to fulfil the mission requirement leading to trajectories with two or three boosts. The current mission baseline characteristics are given in Fig. 2.

The former trajectory considered a so called down-range mission with a landing on a barge in open sea. This option has been cancelled due to the complexity to reach the necessary stability performance for a landing and due to the budget impact.

The current reference trajectory under study at CNES is presented in Figure 2

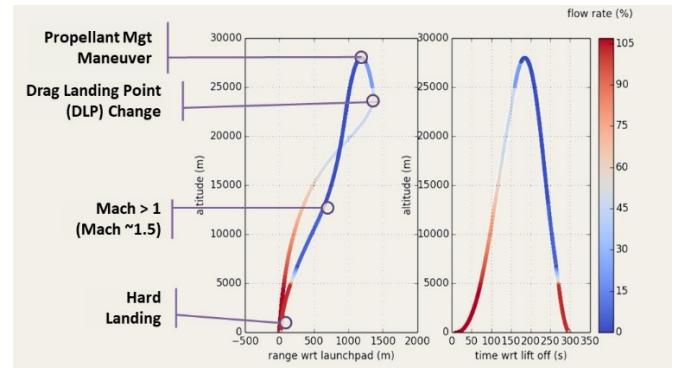


Fig. 2 Current baseline mission profile

This is a two boosts mission. The ‘boost back’ manoeuvre is down before engine cut-off using FCS-V in order to achieve a significant change in the Drag Landing Point (DLP). After engine cut-off, there is a coasting phase up to about 28km altitude. During this phase, the low dynamic pressure allows performing propellant management manoeuvres using FCS-R. Then, the vehicle performs re-entry close to a maximum Mach number of 1.5, with the two objectives of dissipating kinetic energy and reaching end conditions enabling a 15 -25s landing boost during which terminal guidance will be performed to reach metric accuracy. Landing legs are deployed during the landing boost itself. The take-off pad and landing pad are located both on DIAMANT site.

##### 4.2. Flight Test Plan

CALLISTO is designed to achieve the mission requirement objectives. Nevertheless, in order to limit the risk and to learn progressively about the behaviour of the vehicle, to improve the knowledge of the uncertainties... an in-flight test plan is elaborated.

This plan includes 8 test flights and 2 demo flights (5 using the CNES and 5 using the JAXA/DLR OBC and flight software). The plan will allow to open progressively the flight domain, increasing the energy of the mission after each flight.

Among envisaged profiles are very low altitude (“hop”) flights for which vehicle would lift-off directly standing on its landing system, as well as more energetic flight profiles involving vehicle configuration changes.

The figure 5 provides a schematic of the test plan.

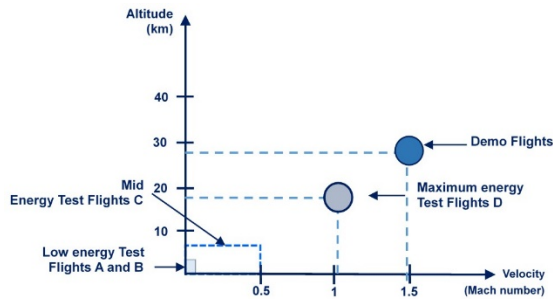


Fig 5. Test flight envelope exploration logic

For the low energy tests, at take-off, the vehicle is supported by its unfolded legs. This allow a low altitude test with hovering using the same launch pad. For the medium up to demo flight, the vehicle will be clamped on a table for take-off. Then the landing pad will be different but closed to the take-off one. The figure below illustrates the two configurations.



Fig 5. Two take-off configurations

#### 4.3. Aeroshape and Sizing environment

CALLISTO Vehicle System design implied the definition of so-called “Flight Domain” for a variety of:

- Flight phases: ascent, re-entry, transients
- Vehicle configurations: FCS/A folded/unfolded, legs unfolding
- Flight profiles: variety of test profiles

These domains are defined for the purpose of putting forward main Vehicle System design drivers and balance design parameters/technical risks.

Vehicle System design have enabled to define an “In Flight Operationnal Flight domain”, within which the Vehicle shall be maintained so as to ensure that it will operate properly during flight.

This domain is the combination of various constraints: Loads, Control capability, Propulsion system capability, Flight Safety.

This domain combines various kind of parameters: Position and velocity states, Load factors, Angle of attack.

This domain has been specified toward guidance and control as the domain within which the vehicle shall be maintained.

Aerodynamic loads need to be characterised as soon as possible by the means of representative Wind Tunnel Tests because, due to the small size of the vehicle the effect of protrusions (lines, ducts, flanges...) is huge on the drag as well as on the lift. On the other hand, it is important to master the uncertainties as soon as possible in order to provide sufficient controllability margins.

The figure 6 depicts the specific areas in CALLISTO that needs dedicated efforts for Aeroshape design.

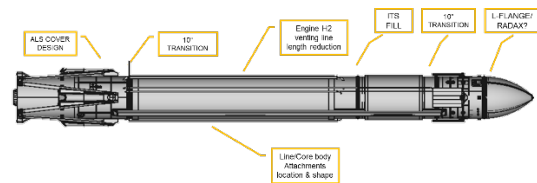


Fig 6 Aeroshape

#### 4.4. Aerodynamic Science

DLR is leading all topics related to aerodynamic science with the support of CNES. It comprises aerodynamic design including preliminary stability and controllability analysis, the improvement of the local aerodynamic coefficients, and the creation of the aerodynamic (AEDB) and the aerothermal (ATDB) database for the vehicle for all relevant flight conditions. For this purpose, a combination of CFD and wind tunnel experiments are conducted. The goal is to efficiently determine aerodynamic and aerothermal data for all the flight conditions that CALLISTO will encounter. This is much more complex than for an expendable launch vehicle. CALLISTO is indeed equipped with deployable subsystems such as the FCS/A and ALS and a throttleable engine. All the combination of deployment status and engine thrust level (including engine off) have to be considered for any angle of attack (see [10]). CALLISTO is for instance flying with engine in the front during the descent. A large number of roll angles needs also to be considered due to the fact that the complex asymmetric shape of CALLISTO.

To generate efficiently the AEDB and ATDB, thousands of CFD computations are being performed with different levels of fidelity. It is worth noticing that in addition to the stationary aerodynamic conditions, the transient phases such as ALS deployment or engine ignition are modelled to better consider their impact on the flight. The large majority of CFD simulations have been carried out using the DLR in house Navier-Stokes solver TAU.

The analyses results are used to optimize the aeroshape of CALLISTO but are also key for the



determination of the vehicle performance and the loads to be expected. As a consequence, a good knowledge of the uncertainties is capital. Figure 7 shows an example of the computed flow field and the surface pressure distribution during the supersonic return phase.

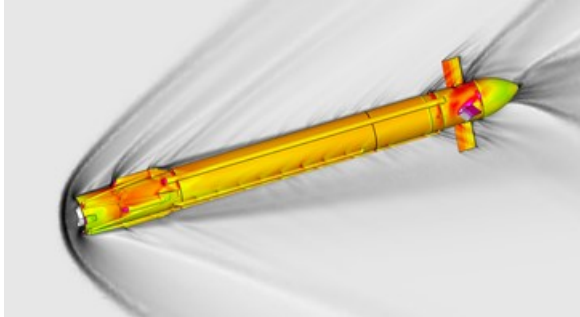


Fig. 7: Computed flow field and surface pressure distribution during supersonic return phase (170 deg AoA, Mach 2).

To improve the vehicle aerodynamics and to reduce the drag in particular several modifications of the outer shape have been performed and studied numerically. Figure 8 shows the surface pressure for an early and late phase aero shape. The transitions between the individual segments have been changed which reduces the drag significantly.

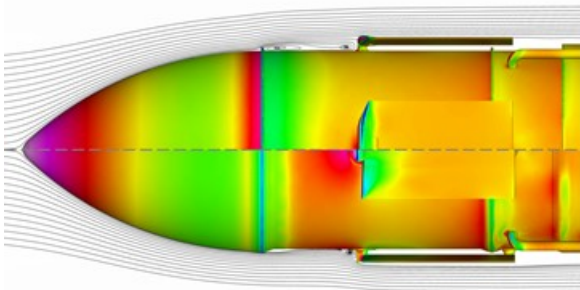


Fig. 8: Aerodynamic improvements. Computed surface pressure for early (top) and later phase (bottom) aero shape (0 deg AoA, Mach 0.7).

The AEDB has been created and is being refined by assessment, evaluation and compilation of CFD data, as well as wind tunnel tests performed at different wind tunnels on different configurations.

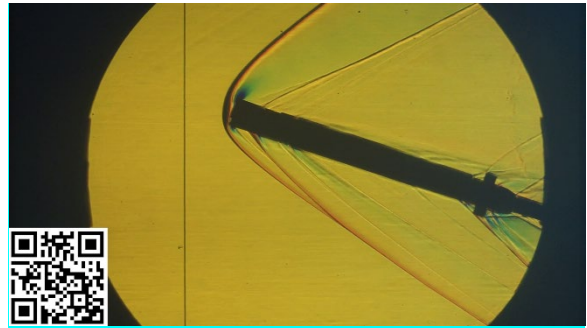


Fig. 9 CALLISTO model in the TMK wind tunnel (top) and example of Schlieren result (bottom) (with link to the video)

In order to reduce the uncertainties of the database wind tunnel tests are performed for different CALLISTO configurations and flight conditions. In 2019 a full test campaign was performed in the TMK wind tunnel at the DLR Cologne for a first design of CALLISTO (CAL1B) at subsonic up to supersonic flight regimes between Mach 0.5 and 2.5 for forward as well as backward facing flight conditions with focus on force measurements and coefficient determination (see [11] & [12]). A second test campaign was performed in spring 2020 in the TMK facility with the focus on in-stationary loads caused by flow separation. The CALLISTO model in the TMK wind tunnel and an example Schlieren result is shown in figure 9. The updated aeroshape CAL1C was tested in summer 2020 in the TMK (small model). The test campaign using a larger scale model in the wind tunnel HST in Amsterdam is currently ongoing (early October 2020). The main goal of this campaign is the determination of the influence of CAL1C protrusions on aerodynamic coefficients and the refinement of the data base at low subsonic Mach numbers. This data should allow adaption of the database uncertainties, and evaluation of the in-stationary loads.

Aerothermal aspects have a large impact on the TPS design of reusable launch vehicles and particular VTVL and must be considered for all vehicle configurations. One of the main differences between a reusable full-size launcher like Falcon 9 (see [13]) and CALLISTO is the relatively low Mach number encountered by CALLISTO during the descent phase. This means that aerodynamic heating during the trajectory is minimal and almost all design driving thermal loads are due to the interaction of hot exhaust plume with the vehicle during the retro boost.

The engine and flight conditions relevant to high thermal loads due to plume vehicle interaction include:

- Plume-vehicle interaction at engine idle mode
- Plume-vehicle interaction at engine throttle conditions (20-110%)

- Plume-vehicle interaction on powered return trajectory at 110% engine throttle
- Plume-leg interaction during flight with open legs (at various leg deployment angles)
- Plume-leg interaction at launch and landing site
- Plume-ground interaction during landing for prediction of radiative heat loads

The influence of the angle of attack on the thermal loads during the retro-boost is shown in figure 10. The influence of plume ground interaction is shown in figure 11. These detailed aerothermodynamic analyses of selected conditions and configurations using CFD allow determination of global and local thermal loads and are the basis for generation of the ATDB used for system and product level activities.

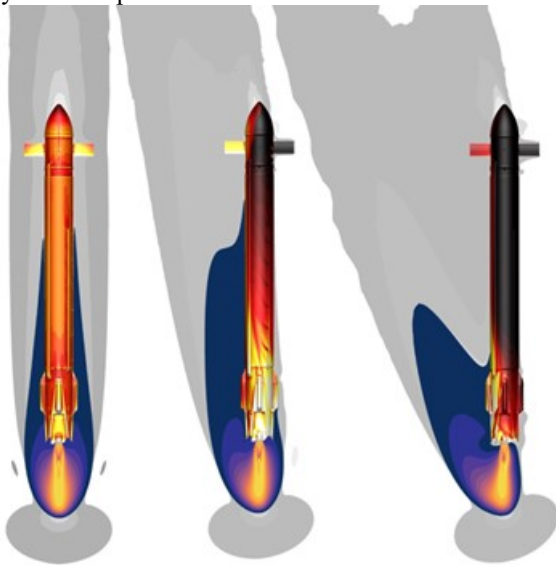


Fig. 10 Thermal loads at 110 % thrust level for 180, 170 and 160 deg AoA (left to right) at M 0.8. Grey scale contours indicate Mach number, blue-orange scale indicates plume temperature, surface contours indicate surface heat flux.

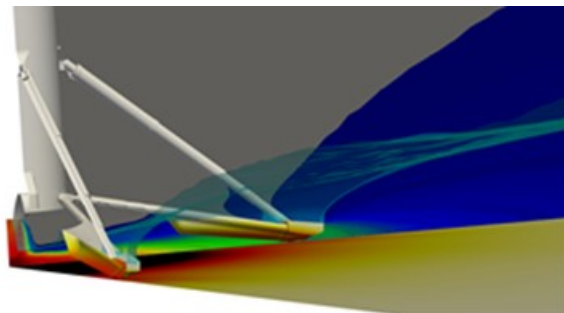


Fig. 11 Thermal loads at 110 % thrust level for a ground case. Rainbow scale indicates temperature, surface contours indicate surface heat flux and turquoise isoline indicates region with over 99% exhaust gas



Fig 12 Large CALLISTO model at CSTB WTT (Jules Verne)

CNES is going to perform wind tunnel tests at CSTB in Nantes. These tests will be performed at low Mach numbers ( $< 0.3$ ) with different configuration (folded and unfolded devices) and with simulation of the ascent phase when the velocity is low at culmination (model attached at the base) as well as simulation of the approach and landing phase (model attached by the nose). The objective is to characterise the low velocity, high Reynolds and high angle of attacks in order to characterise the aerodynamic coefficient and assess the potential wind effect during the flight.

#### 4.4. Landing system and touchdown dynamics

Landing and touchdown simulations play then a large role to understand and trade the strong interaction between the GNC and the ALS capabilities.

Landing system and touchdown dynamics: from system perspective, the ALS enables a safe transition from flight state to ground state during landing. Hence, its main system level function can be summarized as “mastering landing dynamics”. For this purpose, it shall

- (i) provide static & dynamic tip-over stability,
- (ii) attenuate loads transferred to vehicle,
- (iii) ensure minimum ground clearance, and
- (iv) absorb the residual kinetic energy.

For Test Flights A and B, it acts also as a stable platform for launch. The landing system features a footprint of 5.2m, an initial ground clearance of 1.1m and an energy absorption capability of 25kJ. Touchdown dynamics is a central element of the VTVL system design as it is determined by the interplay of several vehicle elements and subsystems, but predominantly by the ALS product (through its most visible elements, the landing gear), the aftbay module, forming the landing platform together with the landing legs, and the GNC system and trajectory design which drive the initial touchdown conditions. Figure 13 depicts a typical touchdown sequence

obtained from DLR’s high fidelity numerical touchdown simulator.

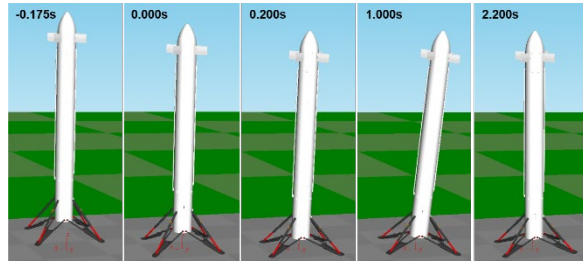


Fig. 13

CALLISTO touchdown sequence: touchdown occurs here at  $t = 0$ s, majority of energy is absorbed within first 250ms, residual energy and associated vehicle motions have decayed about 2s later

#### 4.5. Guidance and Control

The control system consists of the guidance function which computes and evaluates the trajectory and the control function which tracks the trajectory and determines the actuator commands. Depending on the flight phase the trajectory can be fixed and pre-computed or it can be generated on-board in real-time. Difficulties can arise due to the uncertainties involving the aerodynamic coefficients (especially during the descent phase). Moreover, wind has to be considered, as strong gusts or shears can lead to significant deviations from the nominal angle of attack and a trade-off between load relief and tracking performance need to be considered.

Structural limits must also be included in the design of the guidance and control system to preserve the integrity of the vehicle (e.g., the dynamic pressure cannot exceed some prescribed upper bound, and the deflections of the fins must be limited to avoid excessive aero-thermal loads). Finally, accurate touchdown conditions must be met. Therefore, a perfect coordination of thrust, position, attitude and velocity are required to ensure that the touch down impact does not exceed the structural loads that the legs and the aft bay can withstand.

CNES on one side and DLR& JAXA on the other side are developing two independent G&C systems.

The control system developed by DLR and JAXA is based on a point-wise linearization of the equations of motion around the nominal trajectory. The state-space representation is applied to schedule controllers based on linear time invariant (LTI) systems obtained from the linearization of the non-linear model. Well-known stability concepts like Gain Margins and Phase Margins can be used to verify the robustness of the control law. A gain-scheduling approach allows for the extension of the LTI control laws to nonlinear systems while at the same time maintaining a relatively low complexity of the solution. This simplifies the verification and validation of the G&C system. The

gains are scheduled on a monotonic variable like e.g. dynamic pressure, Mach number, non-gravitational velocity (defined as the integral of thrust / mass) or altitude.

A robust control design is implemented by using a well-known control architecture (e.g. PID) which is tuned through a structured robust-control theory-based approach [14]. A typical control architecture based on this concept is depicted in Fig. 14. The guidance solution (indicated with  $r$ ) is tracked by the robust feedback control system which counteracts disturbances ( $d$ ) and noise ( $n$ ). The system output  $y$  is used to compute a feedback control action that drives that the actual state to the reference one. Further details concerning the DLR&JAXA G&C design for CALLISTO can be found in [15], while more details on structured control for ascent vehicles is available in [14] and [16].

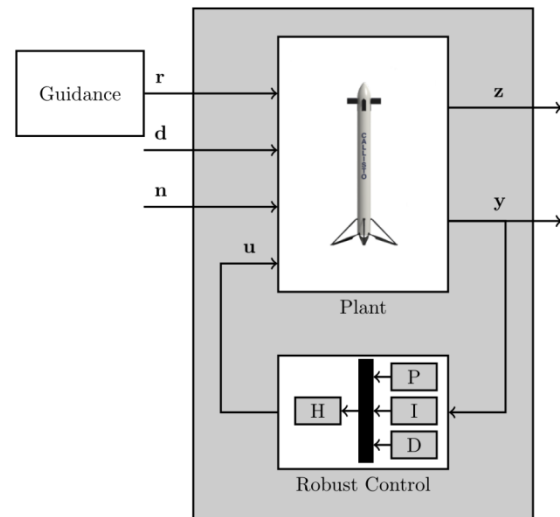


Fig. 14

#### 5. Vehicle

The main characteristics of the vehicle are given in Table 1.

Table 1. Vehicle main characteristics

Item	Value	Unit
Diameter	1.1	m
Total length	13.5	m
Dry mass (req.)	1520	kg
Engine Thrust	44	KN

The CALLISTO vehicle design is very complex and challenging. This is due to the engine performance constraint, that limit the size of the vehicle. To accommodate all the necessary equipment in the allowed volume and to fulfil the mass and centring requirement becomes a day to day challenge. On top of these first order constraints, the vehicle is reusable that



means that the design shall comply with MRO requirements.

We will focus on few products to illustrate the challenge.

The 1<sup>st</sup> product is the VEB module constituted of:

- The VEB structure
- Part of the cable duct
- The FCS-A (fins, actuators, harness, controller)
- The FCS-R (tank, thrusters, carrying structure, fluidics, harness controller...)
- The avionics (OBC, HNS, Harness, Ethernet bus, controllers, antennas, power sources...)
- The flight neutralisation system (tele command receivers, radar transponders, safety kit and safety controller, GNSS...)
- Conditioning system

Many trade-offs were necessary to define and select the VEB layout acceptable from:

- Mechanical standpoint
- Functional requirement for IMU for instance
- Assembly, integration and tests point of view
- Maintenance, refurbishment and operations standpoints, in order to fulfil the operations requirements duration.
- Safety constraints, e.g. filling/draining the H<sub>2</sub>O<sub>2</sub> used for the FCS-R, geographic segregation between the 2 safety chains...

The VEB layout is partly illustrated in the following pictures.

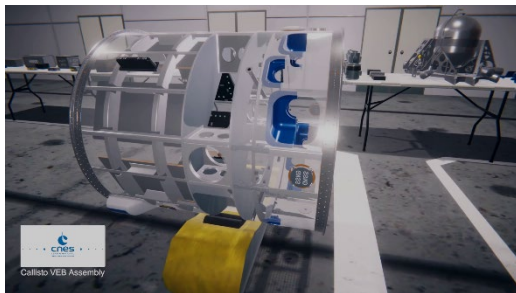


Fig 15. Bare Structure



Fig 16. Bottom view with integrated avionics Structure



Fig 17. VEB Layout with FCS-R power sources, FCS-A actuators

The second product is less a challenge than an innovation. It concerns the smart detonator (DFI) that will be used to initiate the pyro-cords for the termination of the mission in case of safety issue.

Since many years, CNES has supported the development of new solutions for pyrotechnic system and devices used on launchers. The pyronumeric concept has emerged as a good candidate combining the advantages of numerical potential and soft pyrotechnics through the use of nanothermite. The result is a light and miniaturized device, much simpler to implement and to control, and integrating safety management. This technology could replace the historically used on launchers detonator, pyrotechnics transmission lines and the safe and arm device. The DFI integrate in one assembly all these component and functions.

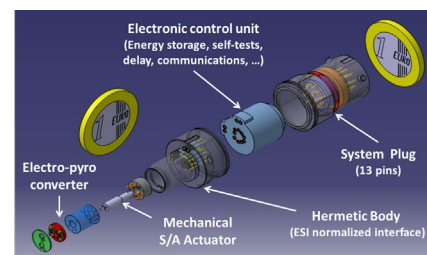
The architecture of the function that is to transmit a termination order is based on:

- A pyro master part of the safety controller
- A communication bus CAN
- A DFI (including mechanical safety barrier and detonator)

The DFI brings several advantages:

- Mass and volume reduction, facilitating layout (on a classical launcher mass saving is about 70%)
- AIT operation in safe condition with simple interfaces
- Controls of the state for the complete system will be simply managed with the numerical pyro master.

All these advantages are of prime interest for CALLISTO considering its constraints.



Courtesy DASSAULT

Fig 18. DFI overview





*Courtesy DASSAULT*

Fig 19. Integrated DFI

For several equipment and in particular avionics, CALLISTO will use COTS. COTS are very interesting in terms of NRC as well as RC for operational systems.

In the case of a demonstrator we want to take benefit from the budget advantage in development, we don't have exploitation phase, but CALLISTO is reusable.

So, despite the benefits of COTS, we face several issues:

- CALLISTO as launcher demonstrator generates more severe ambient than the ones found in the COTS datasheet. This needs to adapt the layout and the vehicle definition in order to reduce the loads impact or to perform delta qualification or to perform a delta development to reinforce the equipment, or several of these options at the same time
- Reliability requirement cannot be demonstrated with COTS without degradation of its benefits. Ambient tests at acceptance level will be performed, including the life duration need. We have also to rely on an appropriate spare policy to manage the reusability objective at vehicle level.

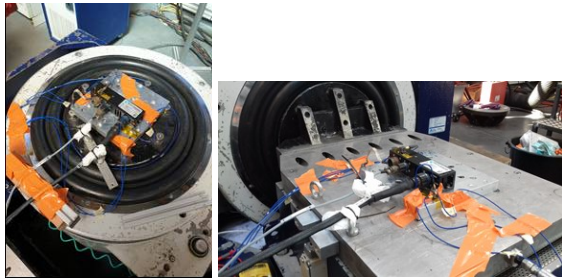


Fig 20. CNES OBC dynamic tests

The rocket engine for CALLISTO RSR-2 will be derived from the RSR-1 developed for RV-X by JAXA. The RV-X firing test campaign is ongoing at Noshiro Test Centre (NTC). The RSR-2 is a LO<sub>2</sub>/LH<sub>2</sub> engine able to modulate the thrust between 16kN and 44kN at sea level and to use idle mode. This engine can be re-ignited and a reusability of more than 100 times has been demonstrated.

During the development long duration firing test will be done at NTC. At CSG only ignition sequence will be tested as well as abort launch.



*Courtesy JAXA*

Fig. 21 RVX firing test with RSR Engine

## 6. Conops

The Operational Concept (Conops) includes operations in Japan and in Guiana Space Centre (CSG).

Focusing on CSG operations, the Conops is challenging and has to fulfil constraining requirements.

It means performing as much as 10 Flights campaigns within a required duration of 6 months considering:

- The launch range (CSG) that is fully operational with a tight launch manifest,
- The vehicle refurbishment to be carried out between two flights,
- The management of LH<sub>2</sub> and LOX residuals inside propellant tanks at landing with as less as possible of on-board functions (safety aspects),
- The management of H<sub>2</sub>O<sub>2</sub> fuel used for Flight Control System/Reaction (or FSC-R).
- The application of ground based and in flight CSG safety rules

The activities at CSG includes:

- Final integration and validation of the vehicle and the Combined Tests, meaning tests in order to validate all the operations involving the vehicle and the ground segment, without take-off, but with ignition of the engine. This is planned to be done within 3 months.
- The test flights and demo flights (5 in total using CNES FSW and 5 in total using JAXA/DLR FSW) to be done within 6 months.

One of the main operation issue concerns the safety conditions after landing. Indeed, once on the landing pad, the vehicle is not connected to any power or conditioning system. The time necessary to reach sufficient safe conditions and to connect by human

operators the vehicle to these services could be long, potentially more than one hour. This duration can involve dedicated on-board solutions to remove potential GH<sub>2</sub> concentration or avoid overheating of the equipment. In order to mitigate this impact on the vehicle it was decided to develop robots that will intervene earlier in the post landing sequence instead of human operators. The robots will shorten the duration necessary to recover safe condition. They will also be used during launch operations.

The Fig 14 gives the sketch of post landing operation sequence leading to a vehicle in safe mode.

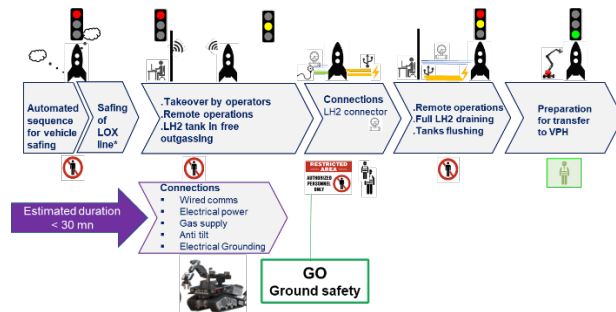


Fig. 14 Post landing operations sequence

The robots will have different functions such as:

- Disconnections and re-connections of 2 fluidic flexible hoses (Gaseous Helium and nitrogen) and electrical harness:
- Disconnection before Lift-Off
- Connection after vehicle landing or abort
- Liquid oxygen collect
- Gas detection (gaseous oxygen and hydrogen)
- Visual inspections and thermal mapping.

## 7. Ground Segment

The decommissioned DIAMANT zone, inherited from the French launcher program of the same name, has been selected to carry out most of the activities.

Cleaning of the area has started all the former facilities are going to be dismantled except the preparatory hall that will be refurbished and reused for CALLISTO for integration and MRO operations.

DIAMANT site will be used for launch and landing operations of the 10 flights. The layout DIAMANT site is presented in Fig. 12. On the right side of figure 12, we see the launch and landing sites.



Fig. 22 DIAMANT current status and future Layout for CALLISTO

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